http://geology.isu.edu/Geothermal/References/FieldTripGuides/
Burnham_and_Wood_1985.pdf, from Field Guide, 1985 Rocky Mountain Section
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FIELD TRIP GUIDE FOR

GEOLOGY OF THE BOISE GEOTHERMAL SYSTEM

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INTRODUCTION

Geothermal water presently used for space heating at Boise is drawn from wells which derive their principal yeilds from silicic volcanic rocks. Successful wells are along an 8-mile (13 km) reach of the northwest-trending range-front fault zone at the north margin of the Snake River Plain. The wells are within one-half mile (0.8 km) of this complex zone of normal faulting. Water temperature ranges from 190°F (84°C) at the southeast to about 150°F (63°C) at the northwest. This field trip will visit the sites of the principal wells; and three localities where rock units representative of the western plain and of the subsurface aquifers will be observed in outcrop. The route of the trip is given in Figure 1. The stratigraphic and lithologic sequence as drilled in the principal wells is given in Figure 2 (stop #1) and Figure #2 (stop #4). Figure 1 (stop #1) is a geologic map showing the distribution of geologic units throughout the field trip area.

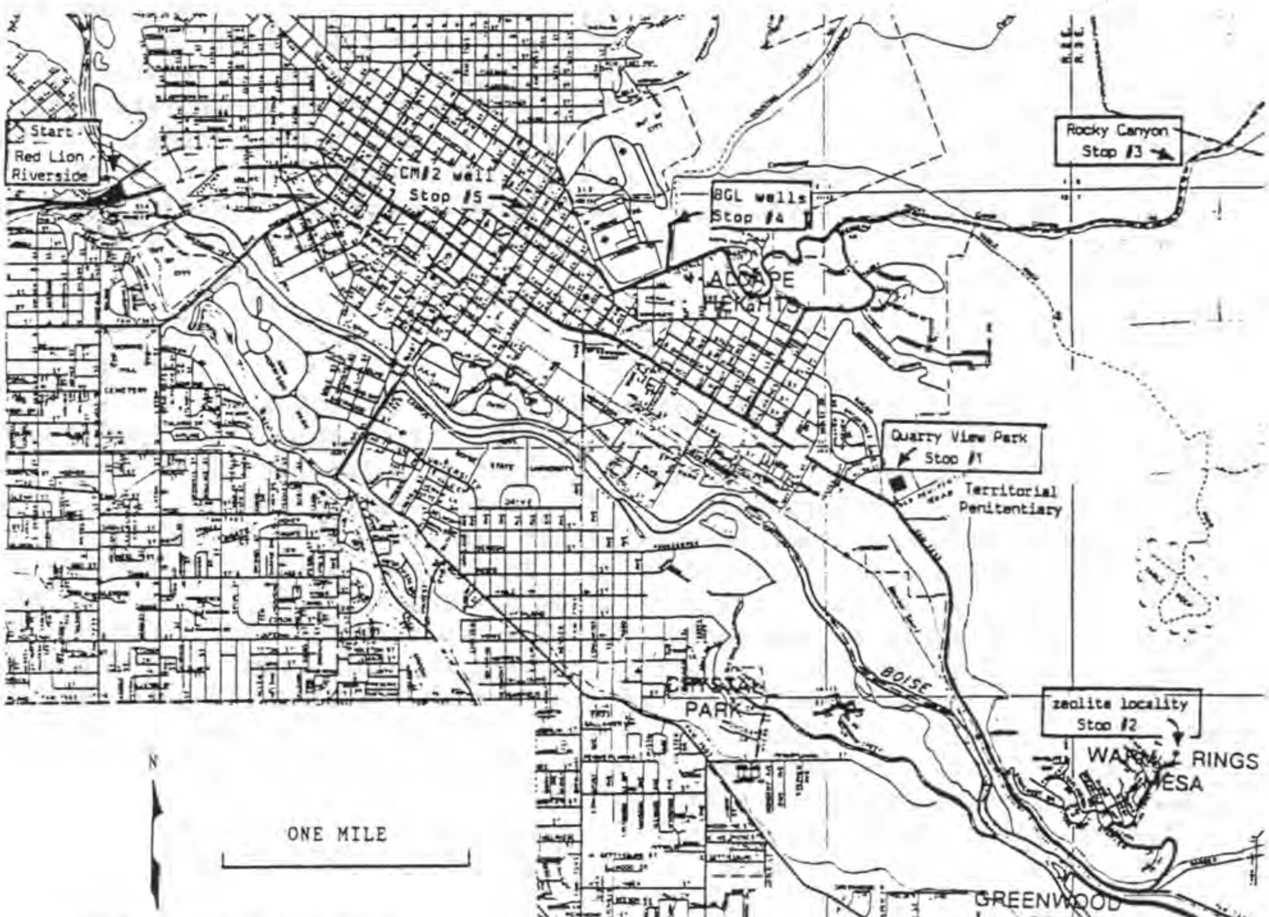

Figure 1. Field trip route.

STOP NO. 1

PENITENTIARY HISTORIC AREA AND QUARRY VIEW CITY PARK, BOISE, IDAHO

LOCATION

The Penitentiary historic area and Quarry View City Park are within the city limits of Boise, Idaho. The locality is accessable by city streets and by morning and evening city bus service. The area is 2 miles (3.2 km) southeast of the Idaho State Capitol building along Warm Springs Avenue (Fig. 1). Turn north from Warm Springs Avenue onto Old Penitentiary Road. Take the first left, about 200 ft (70 m) to Quarry View City Park. Parking and picnic areas are in the park. A major part of the area is a public park administered by the City of Boise and the Idaho Historical Society. The prominant outcrop of rhyolite, locally known as "Castle Rock" is in private land, but at the present time, access is not restricted.

SIGNIFICANCE

Exposed in a long and narrow uplifted fault block that lies immediately north of the park area are representative rhyolite and basalt flow rocks and overlying lacustrine and fluvial sediments of the late Cenozoic strata associated with the western Snake River Plain. The site lies at the northern margin of the Snake River Plain. In the foothills to the north these rocks lap against Cretaceous granitic rocks of the Idaho Batholith (Hyndman, 1980). The volcanic and sedimentary strata are a part of the time-transgressive volcanic stratigraphy proposed by Armstrong and others (1975) and originally discussed by Malde and Powers (1962). Structure at the site is typical of the normal-fault boundaries of the 50-km-wide rift-like basin of the western plain. The fault system is the conduit for 65°C (170°F) geothermal groundwater that supplies the oldest geothermal heating district in the United States. On the site are the original 1892 geothermal well-pump house and the 1870 Idaho Territorial Penitentiary: both are on the National Register of Historic Places.

SITE INFORMATION

Geology

The rocky cliffs north of the park area contain representative rock formations of upper Cenozoic volcanic and sedimentary rocks of the western Snake River Plain (Figs. 2 and 3). The oldest rock at this locality is the rhyolite of Castle Rock. It is onlapped by a 50-ft (15 m) basalt sequence. A poorly-exposed, red-and-green, layered, sandy-clay unit 0-50 ft (15 m) thick unconformably overlies the volcanic rocks. At the top of this sequence is a nearly continuous 20-ft (6 m) bluff of sandstone that extends for several miles along this lowest ridge of the foothills. The fault system that borders the northwest side of the western plain is a complex zone of normal faulting about two miles wide. Rocks at this locality lie in a NW-trending elongate fault block (Fig. 1) that at this locality is about 2000 ft (700 m) wide. Major down-to-south faults also occur south of the "Castle Rock" locality that are now buried by sediment beneath the plain.

The sandstone bluffs appear to be upwarped by the rhyolite mass of Castle Rock (Fig. 4). Waldemar Lindgren (1898) originally reported this feature as a "laccolith in miniature". To interpret this structure as a laccolith the rhyolite would have to be intrusive into the basalt and sediments exposed on the hill. The exposure is not good, and it is understandable how such an interpretation was entertained, especially when his collegue, G.K. Gilbert, had eloquently argued that intrusive bodies of shallow igneous rocks had produced bulges and arches in the roofing strata in the Henry Mountains of Utah (Gilbert, 1877 and 1896; Hunt, 1980). Laccoliths were fashionable in the 1890's, and Lindgren writes:

> "At this interesting locality, well visible from near the Natatorium, the intrusive mass appears as a knob a few hundred feet long and 150 ft high, covered by an arched stratum of sandstone, very clearly uplifted by the force of intrusion. In the cut at the hot-water reservoir the sandy strata near the contact are seen to be locally disturbed, dipping southeasterly at a steep angle. This intrusive appears to form a laccolith in miniature. The rock is dark and glassy, not holocrystalline as would be expected *, and consists of small porphyritic soda-lime feldspars (andesine) and small augite crystals in a brownish perlitic glass with many feldspar microlites."
>
> note* Lindgren did not recognize this rock as a rhyolite, but classified it as an andesite based upon the phenocryst content.

Except for the arched sandstone, as seen from a distance, there is no evidence that the rhyolite is intrusive. Nevertheless, most of Gilbert's criteria for an intrusive laccolith (Hunt, 1980) exist at this locality: 1) no fragments of the (igneous rock) have been discovered in the associated strata..., 2) the (igneous rock) is in no case vesicular .... or fragmental..., 3) inclination of the strata indicates that they have been disturbed...

Two criteria not met by the rhyolite structure here are: 4) .... a sheet (of igneous rock), which for a certain distance has continued between two strata, breaks through one of them and strikes across bedding to some new horizon, resuming its course between other strata..., and 5) the strata which overlie as well as those which underlie laccoliths and sheets, are metamorphosed in the vicinity of the (igneous rock), and the greatest alteration is found in the strata which are in direct contact with it...

The disturbed strata which Lindgren speaks of can be seen at this locality, but they are more clearly disturbed by faulting than by intrusion. The arching of the sandstone can be interpreted as subsequent tectonic warping. The truncation of the basalt against the rhyolite is interpreted as an onlap relationship, and not as an intrusive relationship.

It is a tragedy to slay a beautiful hypothesis with a few more ugly facts; however, the stratigraphy encountered in a number of recent geothermal exploratory wells invariably shows that the rhyolite is overlain by basalt, the clay unit and basaltic tuffs, and finally by the sandstone and siltstone of the lower Idaho Group.

Stratigraphic names of rocks of the western Snake River Plain generally follow Malde and Powers (1962). The interfingering of volcanic, fluvial, and lacustrine facies complicate the assignment of formational names to these rocks. Armstrong and others (1975) have shown a systematic progression of volcanic and sedimentary facies that has migrated from west to east. In that study it is shown that at any one local section one sees (from oldest to youngest): (a) silicic volcanic rocks, mostly as ash-flow tuff deposits with minor basalt and sediment intercalations; (b) basalt flows with minor intercalated sediment and local silicic volcanic rocks; and (c) lacustrine and fluviatile sediments complexly interstratified with basalt flows. Associated with this facies progression is a systematic-age decrease of the rhyolite to the east that has been interpreted by many as a record of the continental lithosphere sliding over a fixed "hot spot" in the mantle at an average rate of 3.5 cm/yr (Morgan, 1972; Suppe and others,1975; Leeman, 1982). A similar facies sequence is exhibited on a much compressed vertical scale at this locality. The oldest rock here is of the upper Miocene Idavada Group of silicic volcanic rocks. The overlying and overlapping porphyritic basalt is similar to rocks that have been mapped elsewhere as the the Banbury Formation, and the lacustrine clay and cross-bedded sandstone is typical of some units of the lower Idaho Group. Because of the age-and-facies progression now recognized across the plain, use of formation names such as the Banbury basalt has led to confusion, and has been discouraged by recent investigators (Wood and Anderson, 1981; Hart and others, 1984)

Rhyolite of "Castle Rock"

The dark rhyolite outcrops on the hill are the upper part of a tabular body of rhyolite that is known from recent drilling to be at least 300 ft (90 m) thick It is encountered in drill holes at a depth of 850 ft (260 m) beneath the Park area and 2000 ft (610 m) deep

EXPLANATION

Correlation of map units

Qal / Qtb	Qls / Qds
Qg	
Qts	
Tils	Tb
Tbt	Tc / Tpb
Tsv1	
Tsv2	
Ki	

Qal	Alluvial deposits within floodplain of modern streams.
Qtb	Alluvial deposits of a late Quaternary terrace of the Boise River.
Qls	Landslide deposits ranging in age from late Quaternary to active in historic time.
Qds	Sandstone layers, folded and disturbed by shallow landsliding prior to the Warm Springs Mesa landslide.
Qg	Gravel deposits of stream terraces generally 16 m (50 ft) above modern streams
QTs	Sandstone, sand, gravel high in the stratigraphic section, but considered part of the lower Idaho Group.
Tils	Sandstone and minor silt layers of the lower Idaho Group.
Tb	Basalt within sediment of the lower Idaho Group.
Tbt	Basaltic tuff, brown in color with interbedded basalt flows.
Tc	Clay, maroon and light green in color with interbedded thin arkosic sand.
Tpb	Basalt, typically contains one or more flows with large plagioclase phenocrysts.
Tsv1	Rhyolite of "Castle Rock"
Tsv2	Rhyolite of Rocky Canyon.
Ki	Granitic rocks of the Idaho batholith.

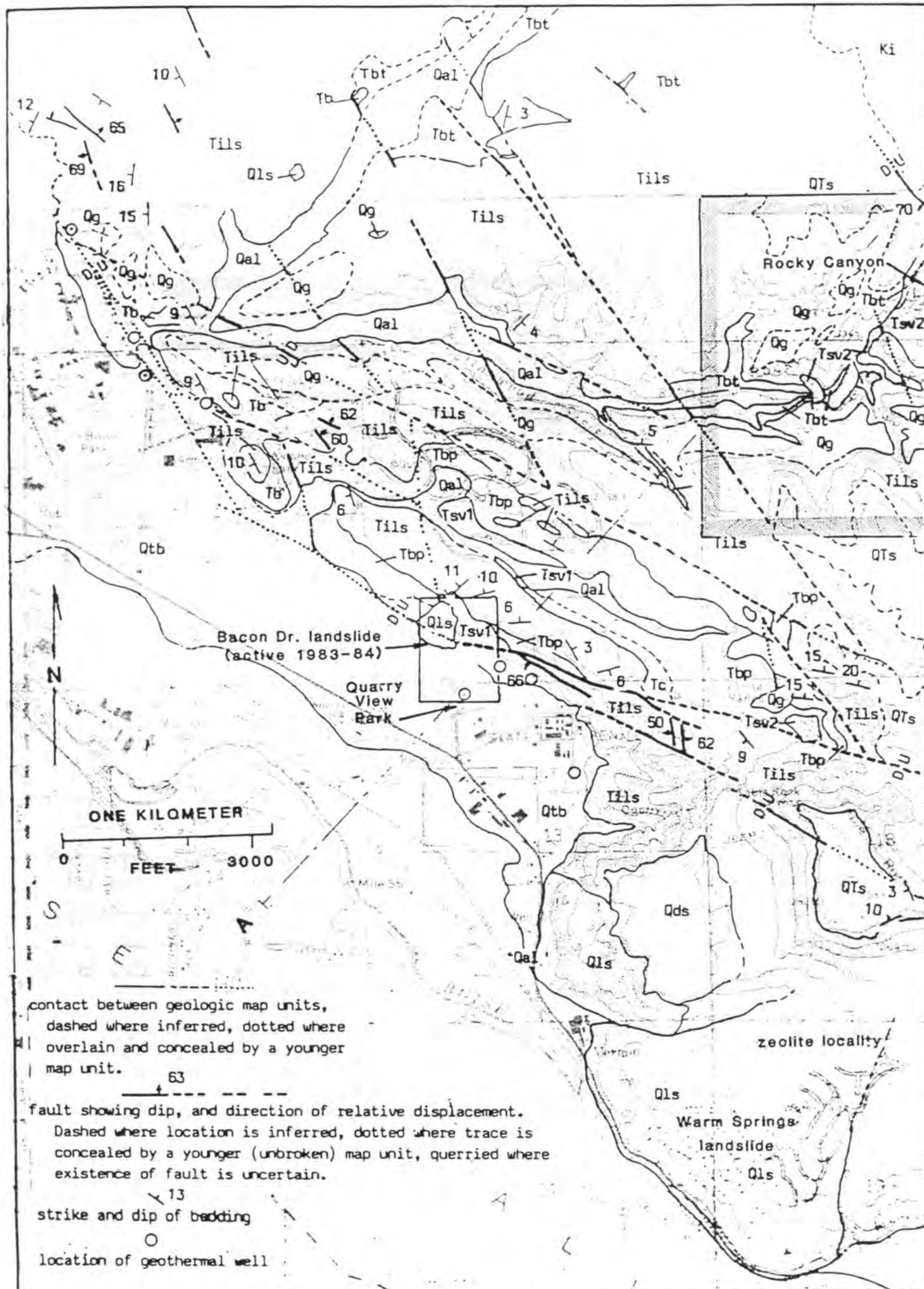

Figure 1. Geologic map of northeast Boise

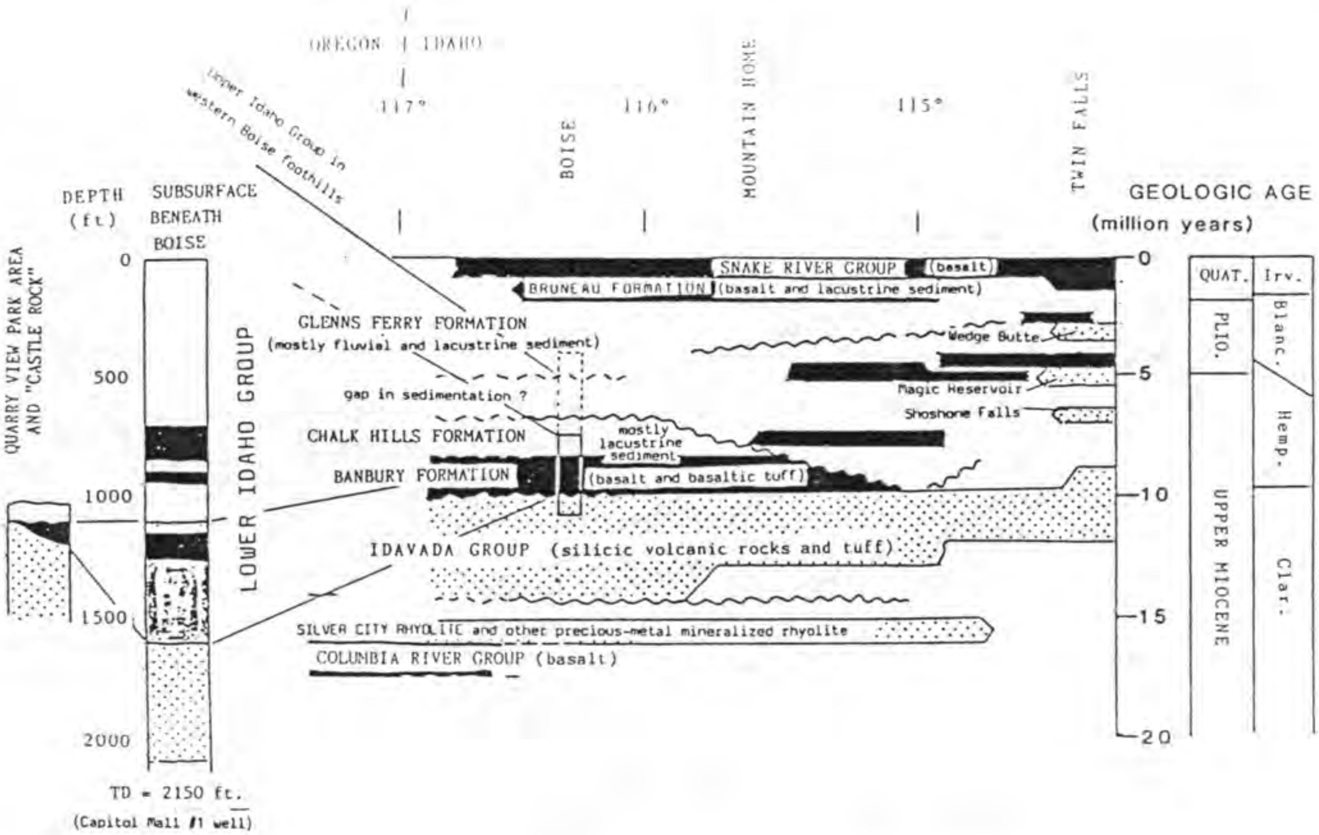

Figure 2. Stratigraphic section for the western Snake River Plain after Armstrong and others (1975), Struhsacker and others (1982), and Malde and Powers (1962), compared to units in the Boise foothills and in the subsurface beneath Boise.

beneath the State Capitol Building, about 3 km to the west.. Two lithologic types occur here. The eastern part of the outcrop is a dark-gray, flow-banded vitrophyre (Fig. 5). The western part and most of Castle Rock is a flow-banded, stony rhyolite with a sheeting parallel to flow banding that causes it to break into thin flaggy slabs (Fig. 6). Mineralogy of the two lithologies is identical. Plagioclase phenocrysts 0.2 to 2mm make up 10 to 15 per cent of the rock. The andesine plagioclase is zoned. In the vitrophyre it appears as transparent amber-colored crystals, but in the stony rhyolite, the andesine plagioclase is deteriorated to a chalky soft-white material. In some rocks the plagioclase has been totally leached away leaving a pitted surface (Fig.7). Minor amounts of magnetite and clinopyroxene (augite) occur as microphenocrysts. It has not been determined whether the stony rhyolite was originally a vitrophyre that has devitrified, or if it was originally crystallized as a stony rock.

Contact surfaces between the stony and glassy rhyolite are steeply dipping. At one locality is a 10-ft (3-m) wide dike of vitrophyre with well developed, horizontal, columnar jointing (Figs. 8 and 9). The dike appears to have invaded pre-exisiting vitrophyre, and may be material squeezed into the already chilled

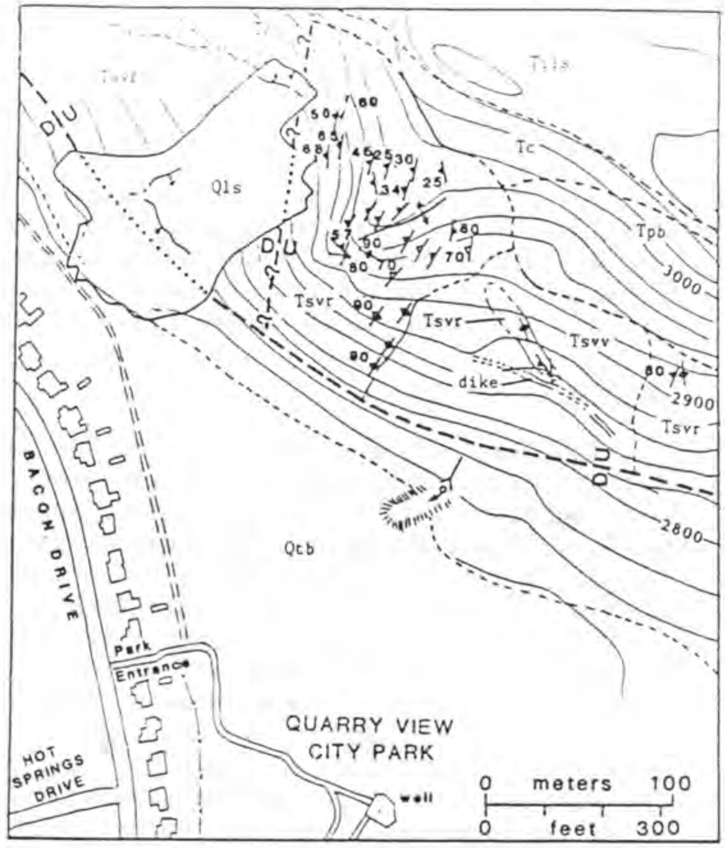

Figure 3. Geologic map of the Quarry View Park area. Foliation is on sheeting and flow banding in the rhyolite. Solid foliation symbol is considered right-side-up, and open sympbol is considered to be overturned. Tsvv is a dark rhyolite vitrophyre, Tsvr is a lavender-gray stony rhyolite, Tpb is porphyritic basalt, Tc is a lacustrine clay and sand unit, and Tils is quartz-cemented sandstone of the lowermost Idaho Group, and Qtb is the Boise River terrace deposit of late Quaternary age.

upper part of the flow. Foliation of flow banding in the stony rhyolite maps into an asymmetric anticlinal structure at least 250 ft (80 m) wide. Because of the widespread and tabular nature of the rhyolite body, it had always been assumed it is a lava flow or a part of sheet of densely-welded ash-flow tuff, and not a dome. However one cannot rule out the possibility that it is a dome with a nearby source vent. It is difficult to distinguish between rhyolite lava flows and densely welded tuffs, particularly when the tuffs have completely remelted and remobilized as lavas. Ekren and others (1984) have shown that these problematic rhyolite lavas are common along the margins of the Snake River Plain. A distinctly different rhyolite body is encountered in drill holes beneath the outcrops (Fig. 12). This older and underlying rhyolite has conspicuous quartz phenocrysts in addition to plagioclase. It is similar to outcrops of stony rhyolite and perlite in Rocky Canyon about 1.5 miles (2.5 km) NW of this area and in the canyon immediately north of Table Rock, just 1 mile (1.6 km) SE of here

Porphyritic Basalt

A body of porphyritic basalt laps against and at places overlies the rhyolite of Castle Rock. It is well exposed in a small quarry area on the slope face about 500 ft (150 m) east of Castle Rock (Figs.3 and 9). The basalt is dark brown with large (3 x 15 mm) plagioclase phenocrysts that are transparent and amber-colored (Fig. 10). The basalt is partly vesicular. Many vesicles and fractures are filled with a variety of zeolite minerals, calcite, clay , and chalcedony. Much of the basalt is discolored and has apparently been altered by geothermal water.

Red and Green Clay Unit

A unit of interbedded laminated green clay, red sandy clay, and arkosic sand locally overlies the basalt. The only good exposure of this unit is in an excavation over the top of the hill, about a 1000-ft(300 m) hike from the park. It can also be reached from Roanoke Drive (see map, Fig.1). In the wall of this pit is a 5-m sequence of bedded clay and sand layers

Sandstone

The clay unit and the basalt is overlain by a 20-ft (6-m) thick unit of cliff-forming arkosic and pebbly sandstone. Much of the sandstone displays cross bedded layers 0.3 to 1 m thick, suggesting that these basal sands were deposited under stream or river-bed conditions. Elsewhere, similar but possibly younger, sands are clearly deltaic in 6-m thick units indicating that water was up to 6-m deep as deltas prograded into a lake system that occupied the plain. A significant thickness of clayey siltstone originally overlaid this sand unit but has since been stripped off of the uplifted fault block by erosion. It is preserved in the subsurface beneath the park area, where wells penetrate about 200 m (Fig. 12). Much of the section of clastic sediments is thought to be preserved in the slopes of Table Rock to the east. Table Rock lies in the same down-dropped fault block as the park area. The capping sandstone of Table Rock is not the same sandstone that forms the cliff-line and the old prisoners' quarry along the skyline above the park. The Table Rock sandstone is much higher and stratigraphically younger, yet both of these well-cemented sandstones have a similar origin. These silica-cemented sandstones in the Boise foothills area always occur within 2000 ft (700 m) of the major fault zones. Cementation is attributed to the percolation of geothermal water, bearing dissolved silica, into the permeable sand layers when they were still confined as aquifers within the less permeable siltstone section. As thermal ground waters migrated away from the faults, they cooled and precipitated silica in the voids of the arkosic sands. Only the relative stratigraphic age of the sandstone is known. It is similar in lithology and setting to the Chalk Hills Formation of the lower Idaho Group on the south side of the Snake River Plain where intercalated volcanic ash layers have been dated by the fission-track method as late Miocene (6.6 - 8.6 m.y.) by Kimmel (1982).

Structure

The site is at the border between the mountainous province to the north dominated by the Idaho Batholith, and the late Cenozoic basin of the Snake River Plain. The margin is characterized by a zone of normal faults several kilometers wide. The fault that runs along the base of the hill beneath Castle Rock offsets the top of the rhyolite unit 800 ft (270 m). Several fault planes can be observed in outcrops of sandstone along the hillside , and back of the Penitentiary Buildings to the east. One fault drops the sandstone datum down about 80 ft (25 m), to form a wedge-shaped plateau of sandstone to the east (Fig. 1). Dip of the fault plane is typically 60° south as measured in the sandstone outcrops. Geophysical evidence discussed by Wood (1984) indicates that other faults lie south of this area in the Boise River valley and have offset the volcanic units to depths of 4500 ft (1370 m).

The Geothermal System

This area is the site of the oldest space-heating development using geothermal water in the United States (Lindgren, 1898; Wells, 1971). One may still observe warm water seeping from the toe of the ridge and from the marshy area of the flats late in the summer at the end of the non-pumping season. These seeps and springs were developed by drilling two wells to depths of 400 and 410 feet in 1890. Originally artesian flow of water at 172 F°(66°C) was piped to a Natatorium and to homes and businesses along Warm Springs Avenue. As artesian pressure declined, pumps were added to the wells. The pump house for the existing Boise Warm Springs Water District wells is built around the bases of the original wooden derricks used to drill the wells (Figure 9). The house was built in 1892 and restored in 1982. During the cooler 7 months of the year, the wells are pumped at an average rate of about 500 gallons per minute~~s~~. Maximum pumping rate for short periods of severe cold weather may reach 800 to 1,000 gallons per minute. The water maintains a near-constant temperature of 170 - 172°F. Seasonal drawdown during the heating season is about 80 feet by April, but recovery is rapid and artesian flow at land surface usually returns by late August. More than 250 homes are currently served: those of long standing being billed a flat rate that is about $400 per annum. Non-patrons of the original district are on metered service at a present charge of $0.57½ per 100 cubic feet.

The source of the heat and the important details of replenishment and circulation of the geothermal ground water have not been clearly identified. At all wells constructed to date the thermal water occurs under artesian pressure in fault zones or fractured parts of the rhyolite and closely associated granular clastic rocks. The basaltic flow rocks and tuffs that overlie the silicic volcanic rocks are invariably altered in major part to clay. This, combined with the overlying siltstone of the lower Idaho Group, forms a capping unit of small permeability for the artesian system.

A conceptual model of the geothermal ground-water systems has been proposed by Wood and Burnham (1983). It is known that some principal fault systems of the area are of regional extent, with cumulative displacement of several hundred meters or more. Many of these structural breaks must extend deep into the rocks of the batholith, thus creating fracture zones of sufficient permeability to permit deep circulation of ground water. The mountainous area north and east of the Boise area are infiltrated by snowmelt and rainwater, and the resulting ground-water system has a high driving head relative to the plain.

The region of the western Snake River Plain is one of high heat flow, thought to result from a thinning of the crust which gives rise to relatively shallow and hot mantle material. Heat flow from within the plain has been measured at 1.7 HFU (heat flow units, calories/cm sec) near the center and 3.0 HFU at the margins as compared with 1.5 HFU for the stable interior of North America (Brott and others, 1978; Lachenbruch and Sass, 1980, Mabey, 1982). The geothermal gradient is typically about 40°C/km over much of this region (Wood, 1984, Fig. 5) and the northern Basin and Range (Lachenbruch and Sass, 1980). Consequently, ground water would need to percolate to a depth of about 2 km to achieve a temperature of 65 C. Water infiltrating the 2,000-m-elevation mountains above the Boise area provides a high driving head relative to the 800-m elevation of the plain, and could concievably drive a deeply percolating ground-water system. The deep hot ground water would then rise along fracture zones and spread laterally through confined layers of silicic volcanic rock beneath the plain.

Although there are many occurrences of volcanic rocks within the area, it is thought unlikely that the source of heat is a shallow magma body in the crust beneath the geothermal area. Rhyolites are probably older than 8 m.y. and the associated basalts only a few million years younger (Fig. 2). Magma chambers in the shallow crust of that age would surely have lost all significant heat within a few million years (Smith and Shaw, 1979). Vents for Pleistocene Snake River Basalt lie within 30 km of Boise, but these appear to be fissure eruptions from deep sources and not evidence for shallow magma chambers.

Should such a conceptual model for the geothermal-water circulation system prove correct, one must accept a consequence of the very limited permeability at such depths within granitic rocks. Thus the volume of water per unit time within the circulating replenishment and discharge system is necessarily small as compared to more commonly developed ground-water systems in granular deposits.

The Bacon Drive Landslide

On about April 2, 1983 the 4-acre landslide just west of "Castle Rock" began moving. Measured rates of movement were typically 0.1 ft/day. The slide stopped moving in July, 1983 and then recommenced about January 15, 1984. The slide stopped by the end of April, 1984 and has not moved again as of March, 1984 (Paul Warner, personal communication). Total lateral movement is about 20 feet. This slide mass had previously moved in prehistoric time, for a somewhat subdued bulge and closed depression were present here before 1983. The initiation of movement appears to have been caused by the saturated slope conditions in the espoecially wet year of 1983. The slide plane probably developed along the clay unit that overlies the rhyolite, however, the geology west of the slide is poorly exposed, and the configuration of contacts is known only from a few drill holes west of this area.

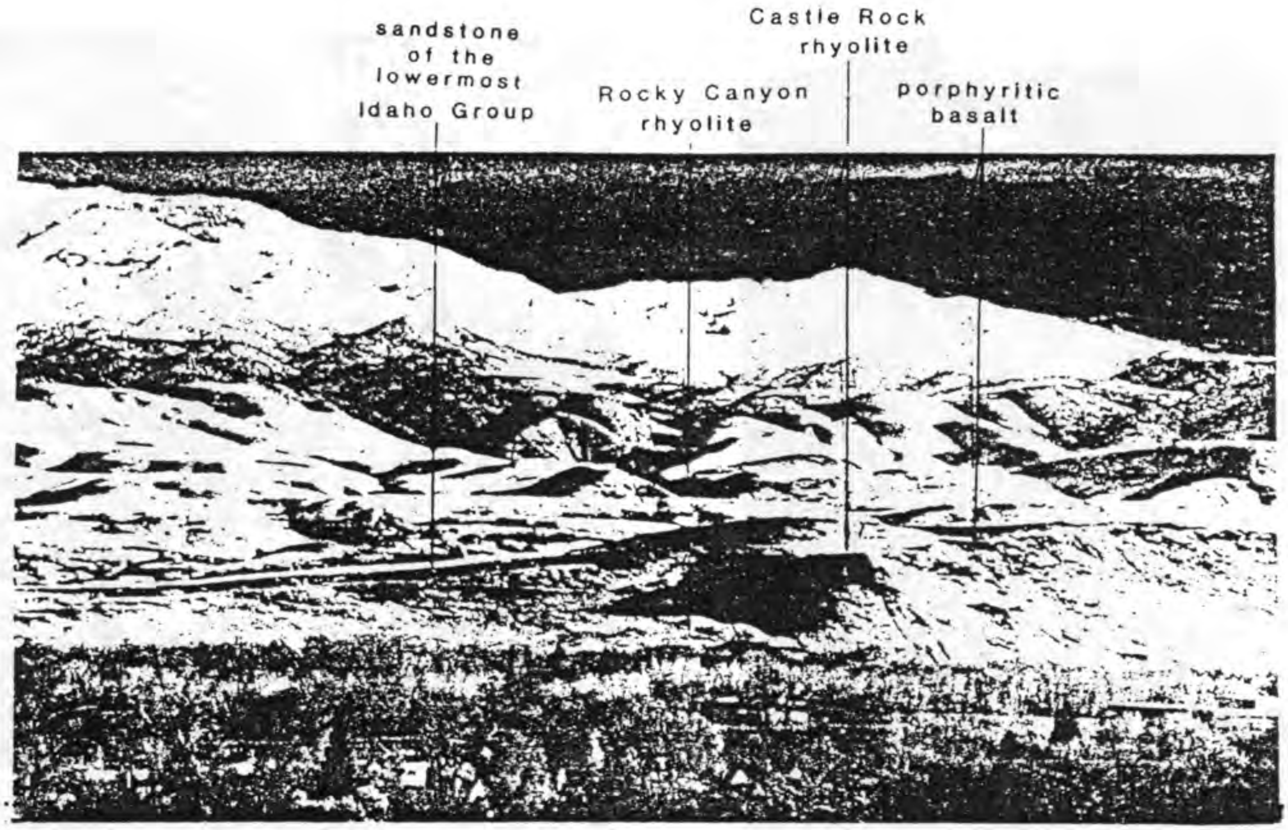

Figure 4. View to the northeast of the Castle Rock area. It is this view of the sandstone-draped rhyolite mass, that suggested the appearance of a laccolith structure to Lindgren in 1898.

Figure 5. Flow banding in the rhyolite vitrophyre.

Figure 6. Sheeting in the stony rhyolite.

Figure 7. Pitted surface of the hydrothermally altered rhyolite caused by solution and etching of plagioclase phenocrysts. The rock is brecciated, and fractures are filled with pale green chalcedony that appears dark in the photograph..

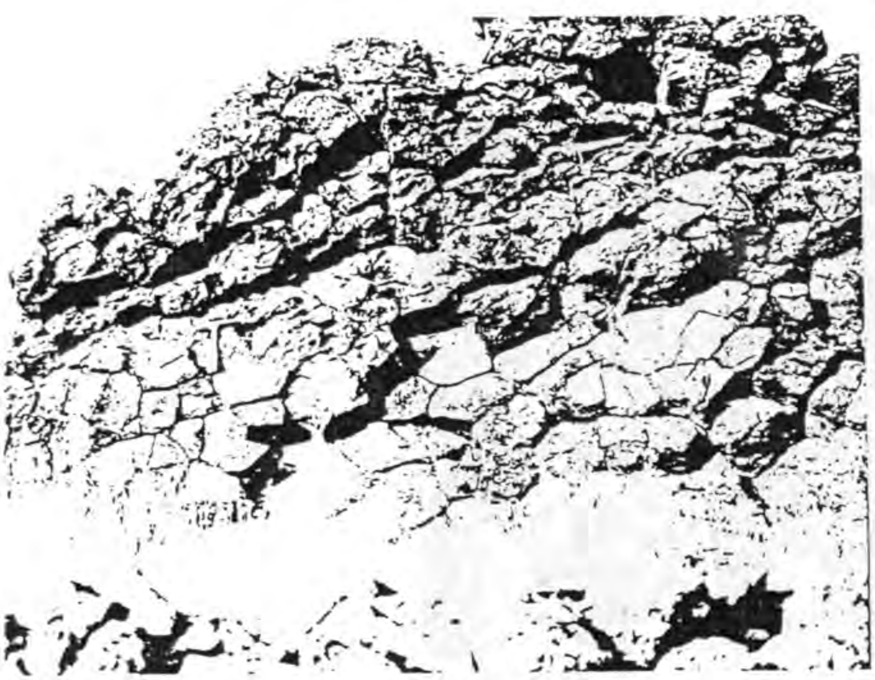

Figure 8. Horizontal columnar jointing in the vitrophyre suggesting this rock was emplaced as a dike-like sheet into pre-existing rhyolite and vitrophyre.

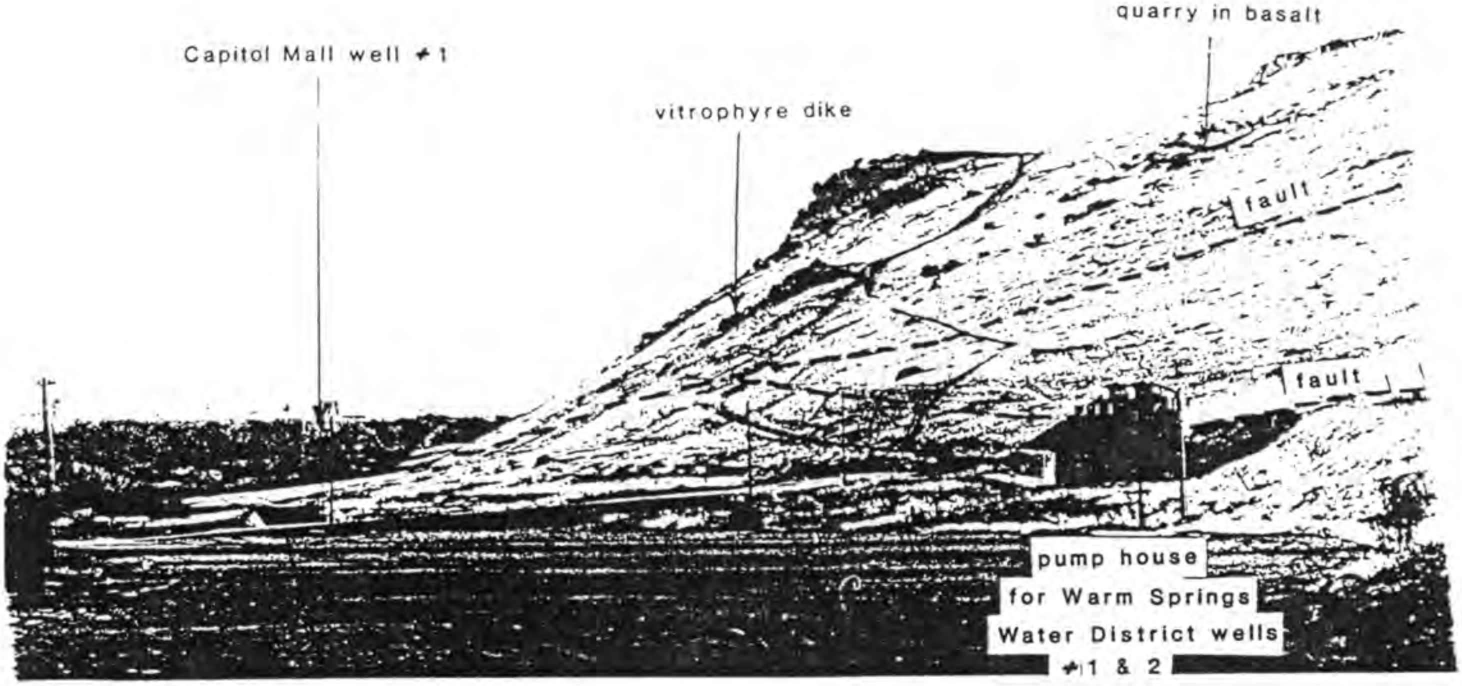

Figure 9. View to the northwest of the Boise Warm Springs Water District pump house, "Castle Rock", and in the background, downtown Boise.

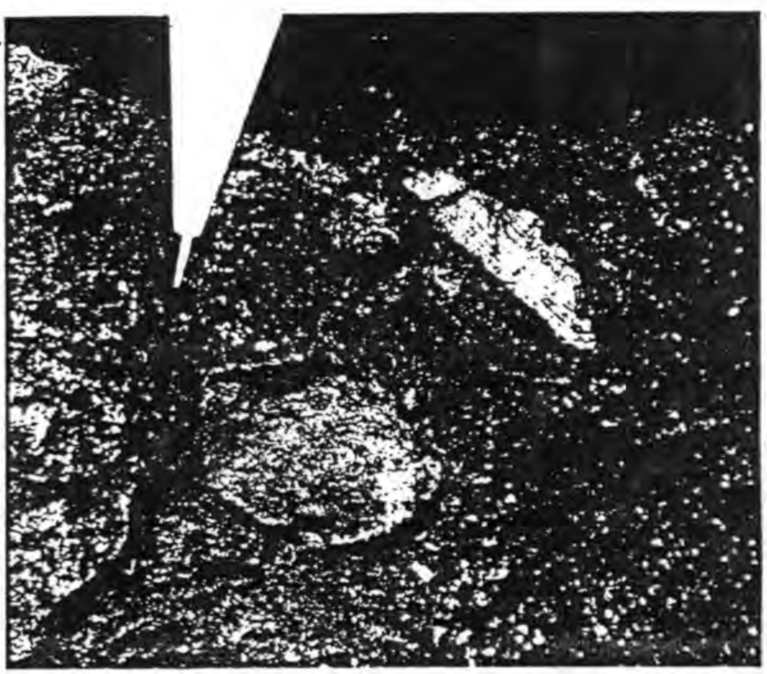

Figure 10. Porphyritic basalt from the "quarry" (Fig. 3) showing a large plagioclase phenocryst exhibiting striations of albite twinning. Pencil points to another plagioclase phenocryst. Spherical area is a clay-filled vesicle.

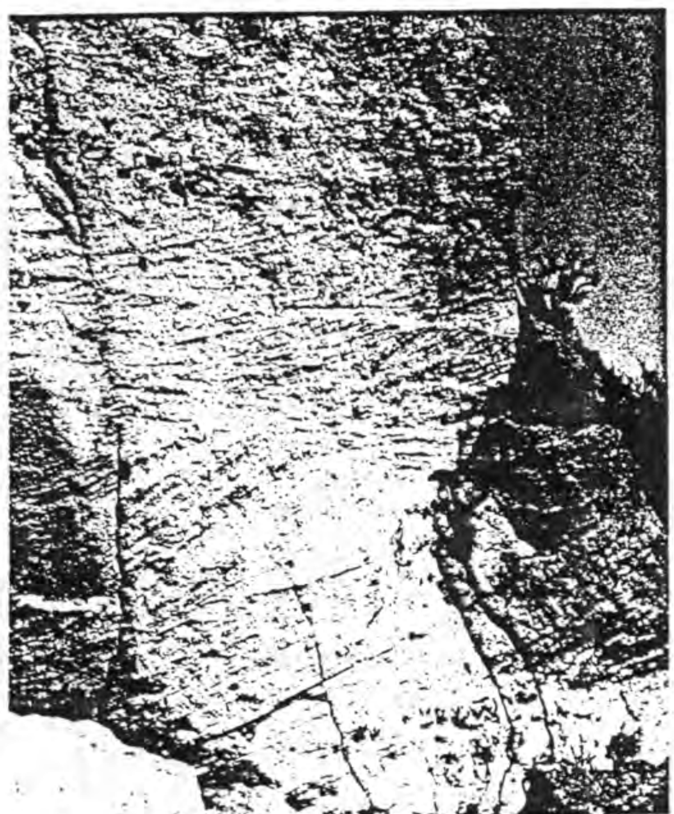

Figure 11. Basal sandstone of the lower Idaho Group showing cross bedding.

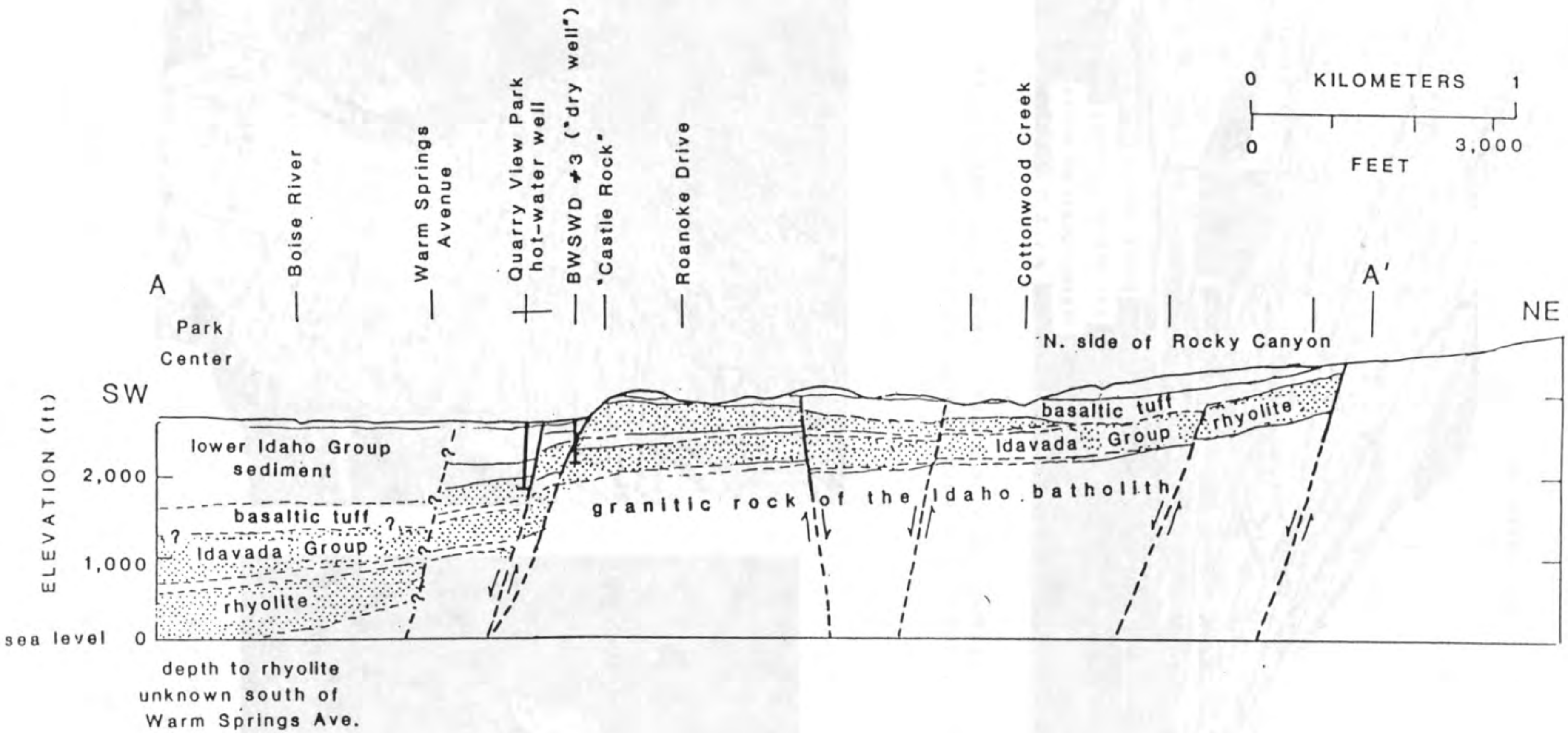

Figure 12. Geologic cross-section through the well at Quarry View Park. Location of section is shown as line AA' in Figure 1.

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STOP #2

Warm Springs Mesa and fossil hydrothermal effects on arkosic sediments.

LOCATION

Prominant hill crest 1,000 feet (305 m) east of the north limit of the Warm Springs Mesa Subdivision and 3,000 feet (915 m) southeast of Table Rock. The locality is accessible by Warm Springs Avenue and principal streets of Warm Springs Mesa Subdivision to the north edge of the development.

SIGNIFICANCE

Exposed in the westernmost high outcrops are arkosic sandstone, siltstone and conglomerate of the Idaho Group sediments that display effects of alteration and silica cementation by thermal fluids. Extensive open fractures and bedding-plane zones of weakness display erosional and depositional effects of thermal fluids. Large fault-controlled fractures contain massive zeolite deposits. The silicified sediments are thought to represent fluvial and shallow lacustrine Idaho Group units accumulating over a major fault zone in underlying granitic and volcanic rocks. Thermal fluids rising along the fault zone under large hydrodynamic pressure diffuse vertically and laterally through the permeable sediments and deposit silica cementation as temperature and pressure decline. The large fracture-fillings are ample evidence of the ability of certain zeolites to form under relatively low pressure-temperature conditions. The zeolites here have not been studied thoroughly but are believed to be mainly stilbite and heulandite. Most of the exposures in these outcrops show deposition as massive sand beds or as thick sequences of current-bedded fluvial sand, silt and conglomeratic sand later invaded by silica cement. There are exposures, however, which suggest granitic detritus being deposited in highly silicious hot spring pools.

The outcrops here are the result of erosion of a considerable thickness of Idaho Group sedimentary cover by the Boise River and its tributaries. The hydrothermal effects seen are fossil evidence of similar effects now going on within the thermal water circulation system of the Frontal Fault system to the northwest.

STOP #3

Rocky Canyon Gorge and Picket Pin Canyon Exposures of the basal volcanic rock units.

LOCATION

Three miles (4.8 km) east of the State Capitol by way of Shaw Mountain Road up Cottonwood Creek. The steep-walled bare rock gorge is cut in rhyolite flow and rhyolitic ash-flow tuff equivalent in mineralogy and character to the deepest rhyolite found in the geothermal water wells. The locality is accessable by passenger car by county-maintained graded dirt road from Boise, or from State Route 21 near Robie Creek by way of Aldape Summit. The locality is on the route of the Boise-Idaho City Toll Road to the Boise Basin gold fields of more than 100 years ago.

SIGNIFICANCE

Erosion by Cottonwood and Picket Pin Creeks here exposes the oldest of the rhyolites of the geothermal system; also its contact with the Idaho Batholith. Here also can be seen the depositional contact of both rhyolitic and basaltic tuff on the rhyolite and granite, as well as their relation to overlying Idaho Group sediments. The tuffs and associated basalts and sediments form the confining unit for artesian pressure in the geothermal system. Also here are displayed evidence for major normal faulting, and erosional-depositional features that document varying conditions during accumulation of the lower Idaho Group sediments. Figure 1 shows the distribution of the several geologic units exposed here.

SITE INFORMATION

Geology

The rhyolite of the gorge is the oldest of the volcanic rocks known in or near the Boise foothills. Complex flow banding and other flow features suggest it is a rhyolite flow, although some features are typical of densely welded ash-flow tuff. Fractures and jointing are intense on two sets; one trending about N 30°E with nearly vertical southeast dip, and the other about N 50°W and dipping southwest. The rock varies in color from dark glossy gray brown to a stoney lavendar-gray. It contains euhedral quartz and small phenocrysts of both plagioclase and alkali feldspar, and minor amounts of magnetite and possibly augite. The domestic water well at the house near the top of the outcrop is 420 feet (128 m) deep; 384 feet (117 m) through rhyolite, a few feet of sediment or weathered granite and the bottom in granite of the batholith. Rhyolite, with euhedral quartz and similar lithology, was drilled in wells in Freestone Canyon about one mile northwest and outcrops in a gully on the north flank of Table Rock one mile (1.6 km) to the south. Elsewhere it is known only from cuttings derived from the geothermal wells 2 to 3 miles (3 to 5 km) west.

Wherever seen, the rhyolitic rocks of the periphery of the Rocky Canyon outcrop are composed of pitchstone, perlite, pumicious tuff, rhyolitic ash or pumicious deposits containing spherules of pumicious glass and large lithophysae-like structures. The tuff and interbedded gray ash occur mainly to the east and southeast.

Basaltic tuff and/or a basaltic volcanic mudstone laps unconformably on the rhyolite and the granite of the batholith. Nowhere has evidence been seen in outcrop of sedimentation or significant weathering at the contact. In an abandoned mine adit on the northeast side of the rhyolite outcrop, tuff with slickensides is clearly in fault contact with the granite. More than 250 feet (75 m) of tuff section is exposed in the ridge dividing the two

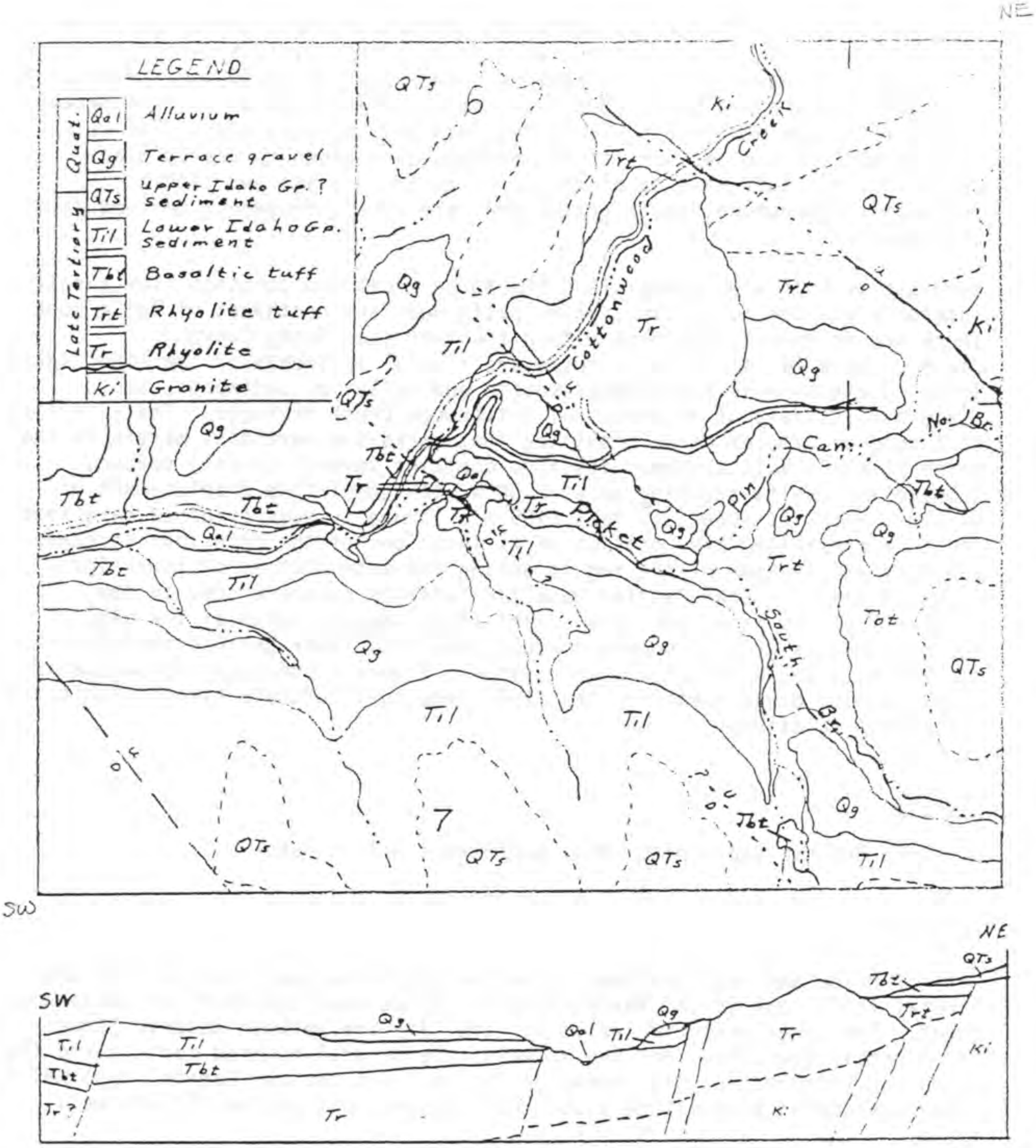


Figure 1. Map and diagramatic section of the Rocky Canyon area, showing outcrops and interpreted subsurface distribution of principal units.

branches of Picket Pin Creek, southeast of the outcrop of rhyolite. The basal 50 feet (15 m) exposed here is largely a brown volcanic mudstone with thin layers of basaltic tuff fragments. The upper 30 to 40 feet (9 to 12 m) is again fine-grained tuffaceous, ashy volcanic mudstone of a light brown color, with distinct bedding including thin beds of ashy clay. The main, central part of the section is well-bedded, dark brown to nearly black coarse-grained tuff made up of shards of basaltic glass and lithic fragments, subrounded basalt grains and rare lithic fragments derived from the granite.

Basaltic tuff is widespread along the Boise Front and contains flow basalt interbeds at some localities, principally near and northwest of Table Rock. There are no basalt interbeds within the tuff near Rocky Canyon. Unconformably on the volcanic rocks are fluvial sediments of the lower Idaho Group, Quaternary-Tertiary fanglomerate and colluvial sediments, and Quaternary gravels of an ancestral Cottonwood Creek drainage. The site lies on a zone of complex normal faulting that marks the northeast margin of the Boise Frontal Fault system. The zone contains several closely-spaced, subparallel faults trending about N 50°W with cumulative displacement of volcanic rocks of about 350 feet (105 m). There is good evidence here that the zone controlled the position of at least one of the principal streams and drainage systems of the region during the accumulation of lower Idaho Group sediments. Down-faulted basaltic tuff was deeply eroded to the southwest of the zone, and lower Idaho Group deposits display the basal boulder gravels grading upward through sands and finer-grained sediments typical of a basin-margin fluvial system. Figure 1 contains a diagramatic cross section drawn normal to the fault zone to illustrate stratigraphic and structural relations.

Stop #4

Military Reserve and Capitol Mall geothermal well sites.

LOCATION

City of Boise and Veterans Administration geothermal wells are within the Frontal Fault zone at the abrupt break in slope near the mouth of Cottonwood Creek. The three producing wells for the City are between Reserve Street and Mountain Cove Road, and the VA wells are several hundred feet toward the northwest (Figure 1). Also shown on Figure 1 are the two Capitol Mall wells along Washington Street some 3,000 feet (915 m) west of the City-VA well field.

SIGNIFICANCE

These modern geothermal wells are the principal suppliers of thermal water for expansion of space heating and other heat energy uses in Boise. Data from their construction, testing and use since 1981 documents surface and subsurface geologic features and the hydrologic character of the hot-water aquifer system, and provides economic and ecological information for future management of the geothermal resource.

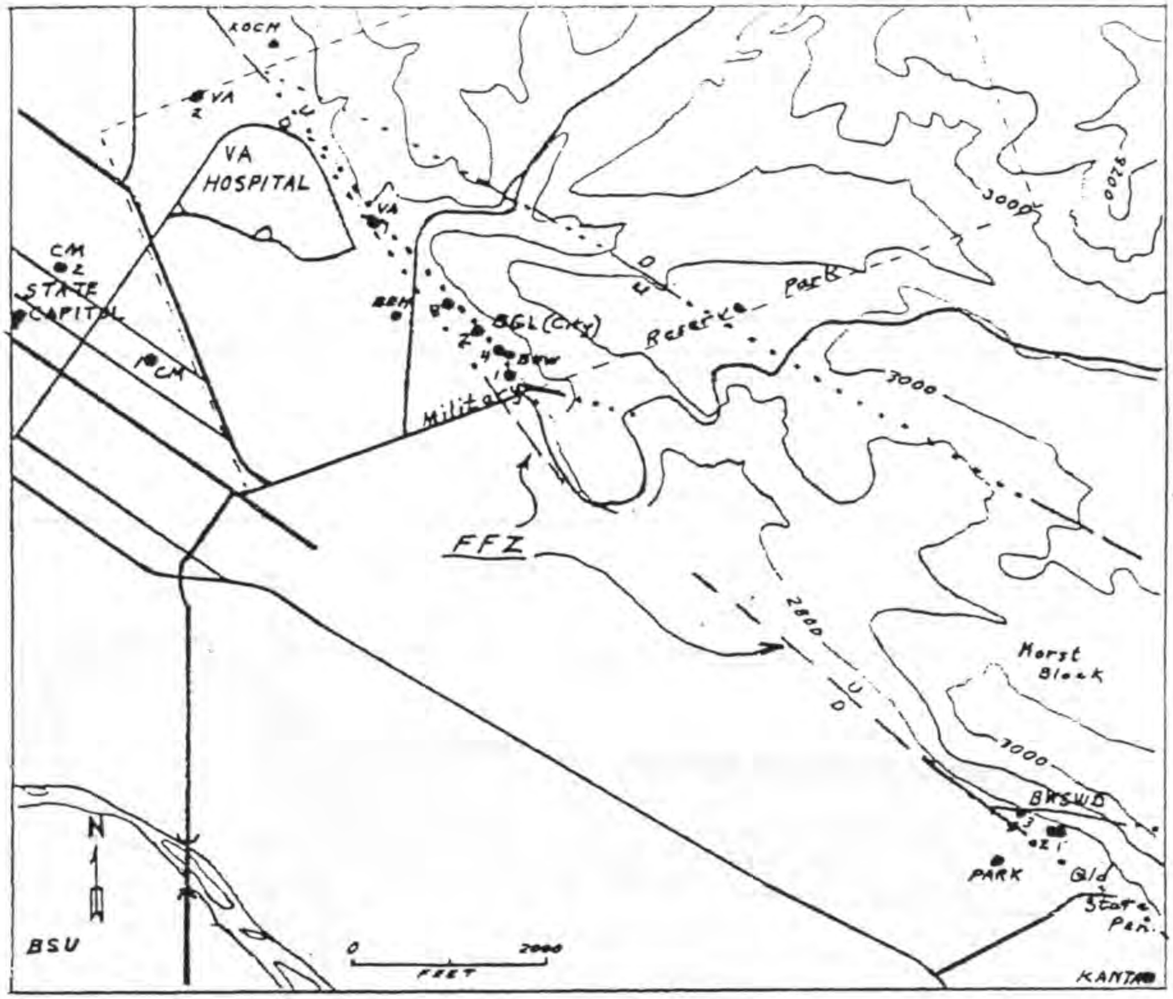


Figure 1. Map of Boise Front area showing location of principal geothermal wells and the Frontal Fault Zone (FFZ) of Hollenbaugh (1973). Capitol Mall (CM), Veterans Administration (VA), Boise Geothermal Limited (BGL-City), and Boise Warm Springs Water District (BWSWD) are the principal production and injection wells. BEH and BHW are test wells for design of BGL well construction. Koch is a small-yield well for space heating of two residences. Kanta is unused. Park is a Boise City Parks well. Only the principal boundary faults of the horst block are shown. See accompanying illustrations for areal structure pattern.

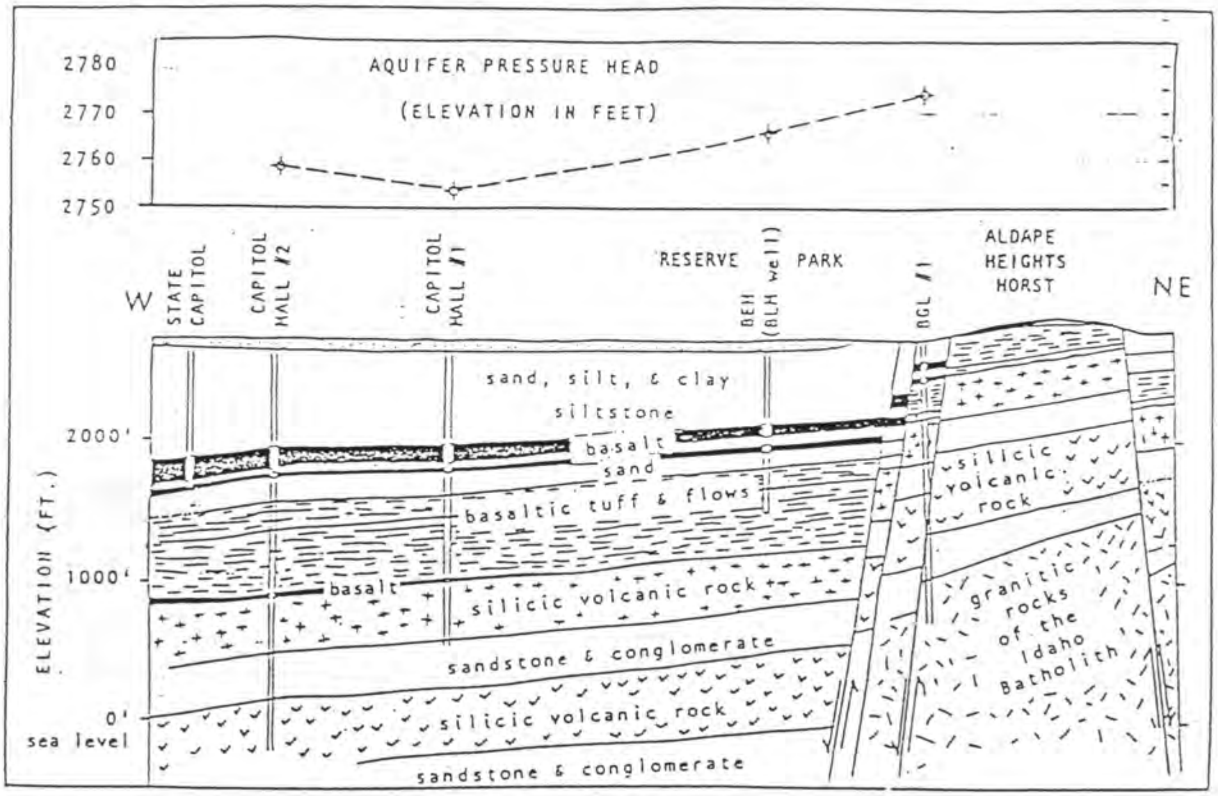


Figure 2. Diagramatic structure section showing correlation of geologic units. See Figure 1 for well locations. Piezometric surface of water at time of well completion is shown above. Section at true scale.

SITE INFORMATION

The Capitol Mall-Boise City-VA complex of wells are all drilled in the same stratigraphic sequence and are completed so as to use the upper silicic volcanic unit and associated sedimentary deposits for production and/or reinjection. The subsurface units and their relative positions are shown on the correlation section, Figure 2. Below a few feet of Holocene alluvium the wells all penetrate from 150 to 800 feet (45 to 240 m) of fluvial and lacustrine sand, silt and clay of the lower Idaho Group, the thickness increasing with distance from the Frontal Fault zone. Below these sediments all wells pass through approximately 400 to 600 feet (122 to 183 m) of basalt and basaltic tuff with interbeds of mixed volcanic and granitic sediment. The basal units of this sequence contain a downward-increasing proportion of hydrothermal alteration clays and generally abundant pyrite. Chalcedony and zeolites are often abundant also.

At more than half the well sites the basaltic sequence contained clean, coarse arkosic sand at the base several feet thick. Immediately beneath the sand (or basalt) all wells drilled a dense silicic volcanic rock from 200 to 400 feet (60 to 120 m) thick. Generally, this rock is intensely fractured, and the majority of the fractures healed with red-brown, orange or green chalcedony. The rock also contains much inter-granular and fracture-surface pyrite.

Arkosic medium-to-coarse sand, sometimes gritty and often stained red, underlies the upper silicic volcanics and is 150 to 400 feet (45 to 120 m) thick. Hydrothermal alteration of feldspars produces variable amounts of gray to white clay in this interval.

The sand unit is underlain by a second silicic volcanic rock that is more clearly rhyolitic, with pumicious and ashy components in the drill cuttings. The rock is more dense than the upper unit and contains euhedral quartz. Where wells drill through this unit the thickness is seen to be about 400 feet (122 m).

Arkosic sand, usually coarse to pebbly underlies the lower silicic volcanic, and at Boise Geothermal Well #1 this overlies granite. Boise City and VA wells are located so as to purposely be completed in or near a major normal fault plane or fault-fracture zone where vertical displacements on silicic volcanics of about 900 feet (275 m) can be shown (Figure 2).

HYDROLOGY

Post-completion testing and production records thus far indicate that the geothermal water occurs and circulates primarily within the fault fracture zones, and the upper silicic volcanic rock and contiguous sand units. Recharge and deep circulation to acquire heat is believed to be as described in the Stop #1 discussion, with the principal upward convection of heated water occuring in or near the main fractures of the Frontal Fault zone. The wells are all completed in different parts of the structural zone and stratigraphic sequence such that regional gradient of static pressure heads is difficult to assess. Indications are that regional movement is northwestward and that natural discharge is probably by upward seepage across the confining basaltic and fine-textured sedimentary layers over a broad area.

The attached illustrations and tables give data on water levels, temperature gradients, water quality and well testing and completion.

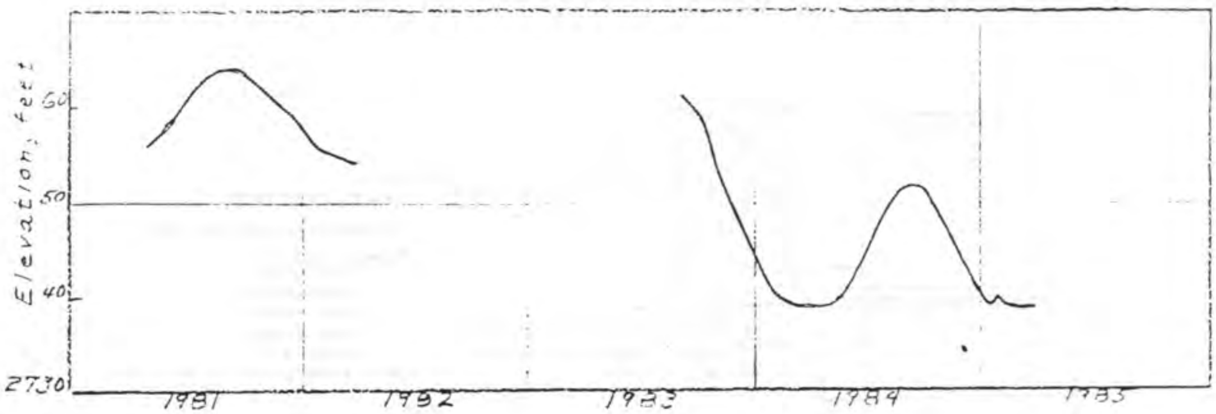


Figure 3. Elevation of static water level above sea level in representative observation well at Military Reserve Park.

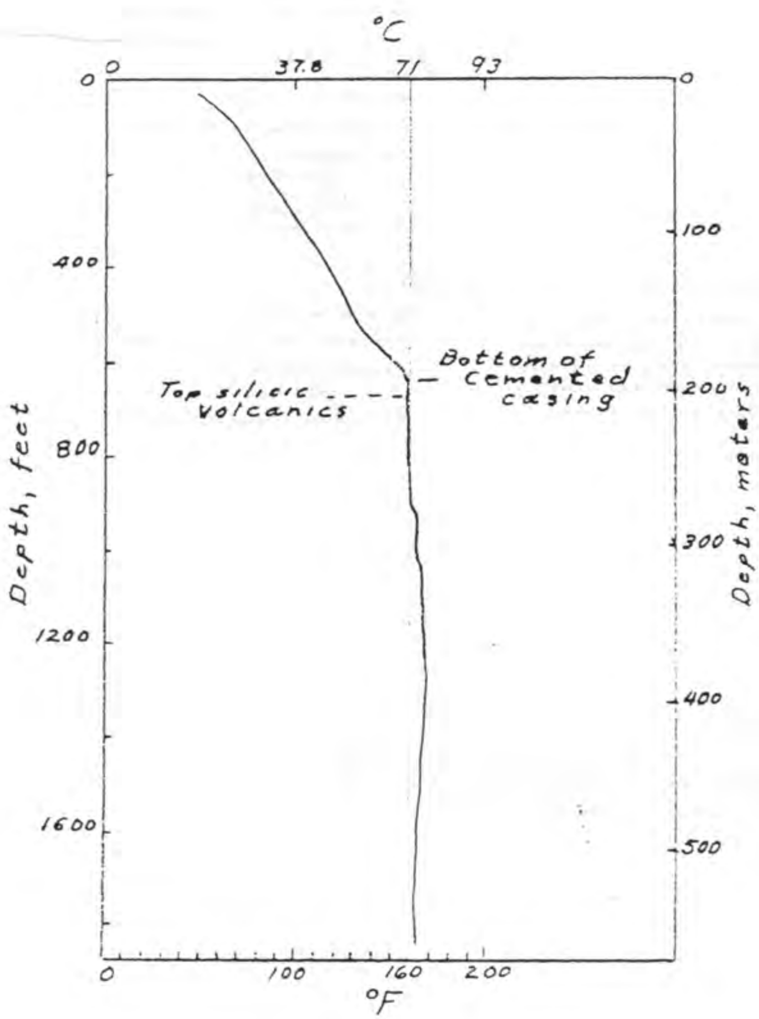
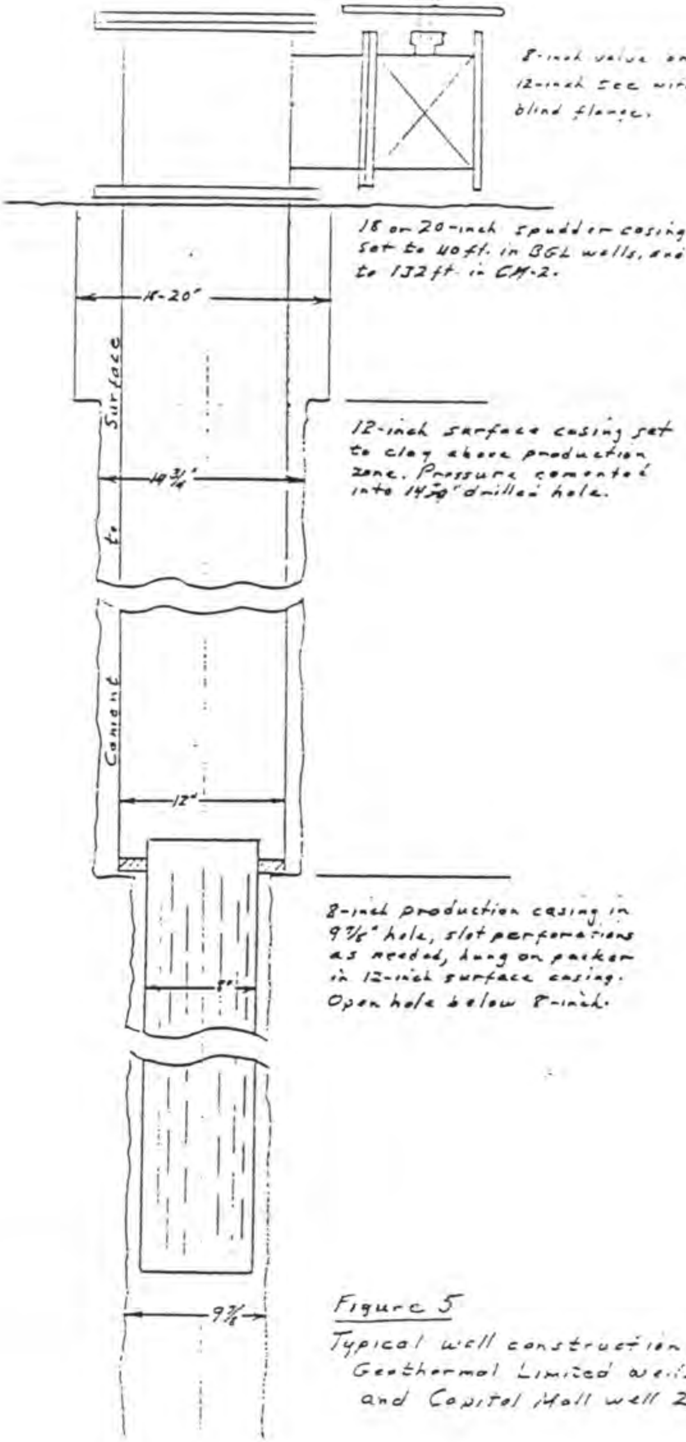


Figure 4. Temperature profile for BGL #3 after shut in for several months. Profile typical of all thermal water wells.



BGL-1
Depth = 2,008'
Surface casing to 857'
Perforations:
857 – 1017
1050 – 1070
1400 – 1500
1530 – 1560
1647 – 1657
Open hole from 1,660 - 2008'

BGL-2
Depth = 980'
Surface casing to 642'
Open hole from 642 – 980'

BGL-3
Depth = 1,897'
Surface casing to 680'
Perforations:
680 – 840
866 – 901
Open hole from 1,050 – 1,897'

BGL-4
Depth = 1,103'
Surface casing to 687'
Perforations:
720 – 800
850 – 870
900 – 1,040
No open hole

CM-2
Depth = 3,030'
Surface casing to 1,258'
Perforations:
1,260 – 2,550
Open hole from 2,550 – 3,030'

Figure 5
Typical well construction for Boise Geothermal Limited wells 1 thru 4 and Capitol Mall well 2.

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Representative Water Quality

(Geothermal & Shallow Cold Water)

	BWSWD (Westwell)	BGL-2	VA Supply	Capitol Mall #2	Barnes (Foothills)	BWCo. Centennial (Valley)	Boise River (Barber)
Specific Conductance (micromhos/cm)	378	405		415	157	208	85
pH	8.15	8.15	8.9	7.55	6.77	7.7	7.29
Temperature, °C	78	74	72	70.5	16	(Cold)	9
Cations (mg/l)							
Calcium	3.2	1.9		1.3	16	21	10.4
Magnesium	<0.1	<0.1		0.1	2.8	0.48	1.26
Sodium	82.6	88		79.2	10.4	23	4.4
Potassium	1.4	1.1		0.6	1.6	0.75	0.9
Silica (SiO_2)	73.5	74		55.6	39.7	27	13
Anions (mg/l)							
Bicarbonate	137	138		142	83	--	46
Chloride	5.9	5.4	9	8	3.6	5	0.3
Sulfate	21.5	20	22	19	10	20	2
Fluoride	19.1	15.7	16.7	16	0.32	0.62	--

Table 1. Representative water Quality, Boise area.

Table 2.

Table 2 gives representative values of transmissivity and storativity for Capitol Mall and Military Reserve wells as interpreted from discharge-drawdown data during flow tests.

Well Ident.	Transmissivity gpd/ft	Storativity Dimensionless
BGL-2	261,000	1.8×10^{-4}
BGL-3	260,000	2.8×10^{-3}
BGL-4	264,000	4.0×10^{-4}
VA-1	120,000-200,000*	-----
CM-1	290,000	4.0×10^{-4}
CM-2	271,000	5.0×10^{-4}
BEH	112,000	5.4×10^{-4}

*Estimated from drawdown effects of pumping BGL-2.

MISCELLANEOUS INFORMATION

Most of the pertinent information on locations, well construction, yield, water temperature and quality, instrumentation, distribution system and uses is given in accompanying maps, diagrams, and table. A few additional facts on design, construction, testing, and completion follow:

1. Data from test holes BEH-1 (BLM) and BGH-1 (Beard) restricted location to near vicinity of interpreted faults striking NW along the toe of the break in slope of the Boise Front.

2. Right-of-way and access restricted locations to roadways and berm tops within Military Reserve Park.

3. Planned uses for Boise City wells determined a desired peak season yield of 2,000 gpm or greater. Test data from the BLM-Beard holes indicated individual well yields of 500 gpm with economically feasible drawdown. Consequently, four wells were needed, to be fitted into available locations.

4. Spacing to minimize drawdown interference between wells had to be matched to access and right-of-way, and to pipeline costs for the gathering system.

5. State and local laws and regulations related to geothermal wells required pressure grouting of surface casing to protect shallow cold-water aquifers, blow-out protection when drilling the thermal zone. Such requirements dictated size, type and capabilities of drilling equipment used. Design discharge and drawdown dictated size of pumps required. Size of pump dictated size cf hole to be drilled to accept casing and the pressure-cemented annulus needed. Size of surface casing was further dictated by size of the production hole and casing needed, and by the possibility that at least two hole-size reductions might be needed below the surface casing. Such considerations further determined the size and type of drilling equipment.

6. Drilling deep, large diameter holes in or near fault zones anticipates hole-wall instability and loss-of-circulation problems. A carefully designed and controlled drilling mud is required. To minimize drilling mud effects on thermal water production, only bentonite clay mixed with fresh water was used where mud driling was necessary. Conditioning additives were closely monitored and kept to a minimum. Wherever possible in the thermal water production zones, drilling was done with water only; with compressed air assistance in removing cuttings and maintaining circulation.

7. Only moderate thermal-water formation pressures were encountered, and as a rule the wells did not flow or make a significant amount of water during drilling. Each well was completed by circulating out the drilling fluid with clear water, then air lifting to reduce the column density sufficiently to intiate artesian flow. Flow was continued until the discharge was clear and stable. Well BGL-3 is located such that the

wellhead elevation is above artesian pressure head. That well was air-lift pumped for completion.

8. The wells were test flowed or pumped under a variety of procedures designed to determine both well and aquifer hydraulic characteristics under planned production schedules and use. Testing included long-term monitoring of water-level changes in the thermal water zones at the Koch well which is drilled in the fault blocks northeast of the Frontal Fault Zone. Also monitored was BWSWD well #3 which is in or near, the faults directly connected to the Frontal Fault Zone and the BLM test hole which is on the valleyward side of the Frontal Fault Zone. During flow tests, all wells in the vicinity completed in the thermal water zones were used as observation wells. Additionally, shallow cold-water wells nearby were monitored for possible drawdown effects.

9. Well and aquifer characteristics, as based on testing done to date may be summarized as follows:

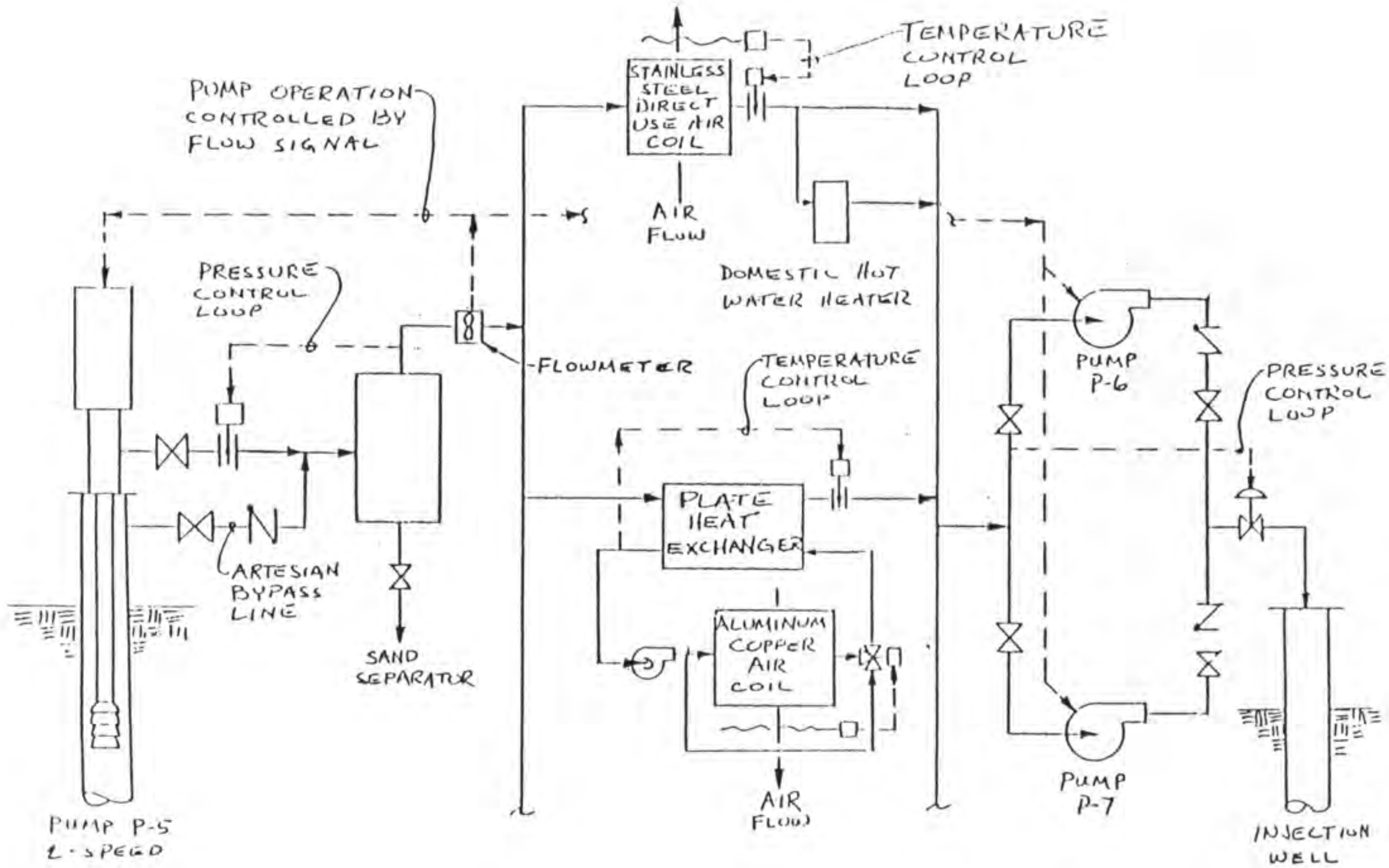
   The wells in Military Reserve Park and valleyward in the Capitol Mall area display a seasonal static level fluctuation that matches closely both timing and magnitude of change in cold-water municipal, domestic and irrigation wells in and near Boise. BWSWD well #3 water level follows very closely the pumping times and magnitude at the two production wells near the Old Penitentiary. (See attached hydrographs.)

   The thermal water aquifer system at the Boise City wells is well confined, with indicated storage coefficients of 10^{-4} to 10^{-3}. All wells have a barometric efficiency of about 80 to 90 percent. During the early, initial period of a test, the aquifer responds as a fault-fracture system with indicated transmissivity in the 10^6 gpd/ft. range and no-flow boundary across the faults to the northeast. Toward the southwest, the Capitol Mall and BLM observation wells indicate the aquifer responds more in the character of a granular material with transmissivity values of the order of 10^5 gpd/ft. and storativity of 10^{-3}.

10. Capitol Mall well #2 was drilled by the same equipment and under essentially the same specifications as the four Boise City wells in Military Reserve Park. The well is 3,030 feet (924 m) deep and bottoms in quartz-rich rhyolite. Attached diagrams and correlative sections give the essentials of well construction and stratigraphic relations. In addition to the geolographic record and cuttings logging, logs were run for Natural Gamma, Caliper, Induction Electrical Resistivity, Borehole Compensated Sonic, Compensated Neutron-Formation Density, and Temperature. These were used to guide production casing, perforation and completion programs. The drilling was done with fresh-water mixed with bentonite mud and/or just fresh water and air. Artesian flow was controlled by mud until wellhead valving was in place and disposal facilities were in order. Upon purging of mud from the column, flow of at least 950 gpm was obtained for initial cleanup and completion. Temperature discharge water stabilized at 160°F (71°C), and shut-in pressure of the hot water column was about 18 psig. The water quality is similar to that from other wells and, following flow tests for data

about aquifer constants, the well was equipped and placed into service for the 1982-83 heating season. Attached information sheets furnish the pertinent information about the well, the heat-exchange equipment in the State buildings and the equipment for injection of the spent water at Capitol Mall well #1.

Capitol Mall well #1 is equipped for injection of the spent thermal groundwater from well #2. Drilled under a separate State contract with light-duty rotary drilling equipment, the well is 2,152 feet (656 m) deep and bottoms in sandstone and conglomerate below the upper silicious volcanic rock. The well was drilled primarily as an exploratory well, and was not designed sufficiently to meet flow needs for heating the Capitol Mall. It does serve well, though, as an injection well. The receiving aquifer is the upper part of the rhyolite at about 1,700 to 1,800 feet (520 to 550 m).



PRODUCTION PUMP STATION

BUILDING RETROFITS (TYPICAL)

INJECTION PUMP STATION

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